DEVOLATILIZATION TEMPERATURE HISTORIES FOR COAL PARTICLES SUBJECTED TO COMBUSTION LEVEL HEAT FLUXES

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ABSTRACT

Devolatilization is an important initial step in virtually all commercial fossil fuel applications such as combustion, gasification, and liquefaction. Characterization of the temperature history of pulverized coal particles under high heating rates, representative of coal combustors, is critical to the understanding of devolatilization.

To this end, 28 single coal particles were caught in an electrodynamic balance and their volume, external surface area, mass, and density were measured. The same single particles were then heated bidirectionally with a pulsed (10 ms pulse width) Nd:YAG laser beams of equal intensity with heating rates (10^4 - 10^7 K/s) representative of coal combustors. The temporal power variation in the laser pulse was monitored for use in the heat transfer analysis by an ultra-fast fiber optic uv light transmitter included in the beam path and coupled to a silicon photodiode. Transient surface temperatures of the particles were measured using a single-color pyrometer. Dynamics of volatile evolution and particle swelling were recorded using well established time-resolved high-speed cinematography. Presently, heat transfer analysis for the devolatilization time-scales, and temperature histories is in progress. In this paper, details of the experimental activities conducted are presented. Also, the modeling activities on-going are briefly discussed.

INTRODUCTION

In all major coal conversion processes, coal undergoes a devolatilization stage while it is heated to the reaction temperature. Recent experimental studies of devolatilization of pulverized coal at rapid heating rates representative of coal combustors have greatly improved our general understanding of this process [1-21]. But the heat transfer analysis with commonly-applied thermal properties developed from slow heating rate experiments did not predict either the early heating or the latter stages of heating [1-3,18-19]. Design of coal combustion and conversion processes require knowledge of thermal properties to construct an energy balance. It is accepted that there are uncertainties in the heat capacity of coal especially for the high heating rate studies [2,6]. It is also accepted that the large thermal gradients within the particle (due to thermal conductivity of coal) make prediction of the temperature difficult during the early heating in these studies [6].

However, there has been no independent study conducted to investigate the effect of heating rate on the thermal properties of coal particles. Knowledge of the role of heating rate on coal thermal properties is essential to progress in advanced coal utilization technology.

The objectives of this proposal are to understand the effect of heating rate on thermal properties of pulverized coal particles. The specific objectives are:

1) Subject coal particles into a broad range of heating rates and extract heat capacity information for high heating rate applications.

2) Also develop thermal conductivity information for coal particles subjected to rapid heating rates representative of coal combustors.

Experiments and modeling are being carried out to meet the project objectives. The successful accomplishment of the above goals will provide better understanding of coal thermal properties in high heating rate applications and hence improved combustion modeling.

In this paper, details of the experimental activities conducted are presented. Also, the modeling activities on-going are briefly discussed.

EXPERIMENT, ANALYSIS, AND RESULTS AND DISCUSSIONS

The laser heating set-up previously available at the Single Particle Laboratory, Federal Energy Technology Center, Morgantown, WV would work only in the range of 10^4 to 10^5 K/s. Details of the measurement system can be found elsewhere [2,18-19]. Appropriate changes were made to heat particles in the range of 10^4 to 10^7 K/s. For this, power attenuator and the charge voltage of the heating laser system were carefully adjusted, beam path reconfigured and aligned, and the laser power characterized to obtain optimum spatial and temporal distribution.

Calibration for all the components of the electrodynamic balance measurement system including single-color pyrometer and heating laser was successfully completed following the procedures described by Maloney et al. [2,18]. Following the calibration, a few coal particles were injected into the balance and by application of ac and dc potentials to the ring and endcap electrodes, a single particle that had a higher charge-to-mass ratio was confined at the null position of the balance. Following the approach of Maloney et al. [21-23], the particle volume, external surface area, mass, and density were measured. The same particle was then heated bidirectionally with a pulsed (10 ms pulse width) Nd:YAG laser beams of equal intensity. Using the approach of Sampath [18-19], the temporal power variation in the laser pulse was monitored for use in the heat transfer analysis by an ultra-fast fiber optic uv light transmitter included in the beam path and coupled to a silicon photodiode. Measurements of changes in particle size that accompanied rapid heating was made by means of the high-speed diode array imaging system. Dynamics of volatile evolution and particle swelling was recorded using well established [2,5,18] time-resolved high-speed cinematography. Measurements of the radiant emissive power from the heated and cooled (when the laser was turned off) particles was made using the single-color pyrometer. Particle experimental temperatures was calculated from the measurements of particle size and radiant emissive power by applying the Wein approximation to Plank's law. The above experiments were repeated for a significant number of coal particles for various heating rates in between 10^4 - 10^7 K/s. Raw size and intensity data for 28 coal particles tested are presented in Table 1.

Table 1. Raw Data for the Laser Heating Experiments

Particle #	Cd/m	Rotaional Area	Rotational Volume	Rotatioal Dp(area)	Rotational Dp(vol)	Laser Det. Power	Side Dp(area)	Side Dp(#line)	Side Dp(#width)	Top Dp(Area)	Top Dp(#line)	Top Dp(#Width)
1	49	26841	326542	93	85	0.629	85	84.8	88.4	77	93.8	70.8
2	52	33015	449444	103	95	0.652	74	115.3	57.4	82	65.9	113.2
3	31	34713	537058	105	101	0.632	95	113.6	84.5	91	77.8	103.8
4	32	36345	543636	108	101	0.638	106	100.1	112.3	107	113.6	99.0
5	22.5	47664	805956	123	115	0.639	123	164.5	93.9	99	105.6	101.5
6	80	75865	1533570	155	143	0.655	144	170.1	142.0	130	126.9	151.5
7	28	41374	691213	115	110	0.651	118	114.2	139.0	103	134.4	75.8
8	35	31006	408401	99	92	0.654	102	159.4	80.4	82	79.7	91.6
9	27	49500	798314	126	115	0.645	100	131.0	82.6	105	84.9	153.0
10	32	34096	518157	104	100	0.662	105	114.9	91.4	81	78.4	95.7
11	36	34933	515043	105	99	0.329	110	100.7	125.9	101	115.4	94.6
12	29	40315	660464	113	108	0.329	125	135.4	138.2	96	134.0	80.0
13	34	33469	464040	103	96	0.4	101	94.6	116.1	96	115.3	90.2
14	27	62815	970536	141	123	0.399	124	104.7	165.9	120	162.3	94.4
15	30	51816	828580	129	117	0.324	109	144.2	88.9	107	93.4	122.9
16	33.5	33664	480307	104	97	0.329	96	101.2	105.8	91	105.9	82.5
17	28	32877	467752	102	96	0.328	101	104.4	95.1	78	87.6	86.2
18	24	48124	859429	124	118	0.599	124	123.8	128.5	107	118.0	106.6
19	33	32180	440987	101	94	0.643	101	97.8	108.9	97	105.9	85.8
20	28	35640	522754	107	100	0.645	109	141.9	102.2	94	105.7	86.4
21	30	36476	559378	108	102	0.567	115	123.8	108.3	94	106.8	77.9
22	23	54042	1013520	134	125	0.569	138	115.1	166.5	138	172.2	113.8
23	28	37595	613923	109	106	0.561	122	111.1	130.2	99	133.1	68.2
24	40	23720	302077	87	83	0.464	84	81.8	96.3	82	96.7	80.4
25	25	49992	820358	126	116	0.473	116	112.2	121.9	139	134.4	143.6
26	26	42853	719152	117	111	0.592	106	137.4	103.6	91	103.5	90.8
27	27.5	39220	619320	112	106	0.652	109	111.8	105.2	106	105.4	111.3
28	26	49225	853388	125	118	0.592	115	140.3	96.7	111	107.2	120.4

Data reduction, and numerical analysis for the effect of thermal properties on the temperature histories are in progress. Details of the modeling procedure including the governing equations and boundary conditions describing the measurement system can be obtained elsewhere [2,18-19]. Several theoretical analyses were conducted to improve the model performance of the present work and the results were compared with data available from our previous studies. These activities resulted in one journal publication [24], three conference presentations [25-27], and one symposium presentation [28]. Joie C. Taylor, an undergraduate student in the Department of Engineering, CAU, was partially supported and trained in the subject matter.

OUTCOMES TO DATE

1. Sampath, R., Monazam, E. R., Maloney, D. J., and Zondlo, J. W., Development of Improved Coal Combustion Modeling: Analysis of Coal Particle Irregularity and Thermal Properties on Temperature Predictions, Fifth Annual HBCU conference organized by FETC/DOE at Southern University and A&M College, LA, March 1997.

2. Sampath, R., Maloney, D. J., and Monazam, E. R., Effect of Heating Rate on the Thermodynamic Properties of Pulverized Coal, Contractors Review Meeting, Fifth Annual HBCU conference organized by FETC/DOE at Southern University and A&M College, LA, March 1997.

3. Taylor, J. C., Sampath, R., Maloney, D. J., Zondlo, J. W., and Monazam, E. R., Transport Phenomena of Irregularly-Shaped Solid Particles in an Electrodynamic Balance, Poster Paper, Fifth Annual HBCU conference organized by FETC/DOE at Southern University and A&M College, LA, March 1997.

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8. Sampath, R., Maloney, D. J., and Zondlo, J. W., Evaluation of Thermophysical and Thermochemical Heat Requirements for Coals at Combustion Level Heat Fluxes, 27th International Symposium on Combustion, August 2-7, 1998, Boulder, CO.

9. Sampath, R., Maloney, D. J., and Proscia, W., Thermal Property Data for Coal Particles for Use in Rapid Devolatilization Models, Technology Transfer Session, Historically Black Colleges/Universities and Other Minority Institutions Annual Symposium, April 28-29, 1998, Ocean City, MD.

10. Taylor, J., Sampath, R., Maloney, D. J., and Proscia, W., Rapid Devolatilization Studies for Coal Particles in an Electrodynamic Balance and in a Heated Grid Reactor, Technology Transfer Session, Historically Black Colleges/Universities and Other Minority Institutions Annual Symposium, April 28-29, 1998, Ocean City, MD.

11. Sampath, R., Maloney, D. J., and Zondlo, J. W., Measurements of Surface Area and Volume for Irregularly-Shaped Coal Particles, Central States Technical Meeting, Combustion Institute, 31 May - 2 June, 1998, Lexington, KY.

SUMMARY AND CONCLUSIONS

Modification of the laser heating system at the Single Particle Laboratory, FETC, Morgantown to heat coal particles at very high heat fluxes with heating rates on the order of 10^4 - 10^7 K/s was completed. Calibration activities for various instruments of the measurement system were successfully completed. Temperature measurements on a large number of coal particles subjected to very high heating rates were made. Data reduction and analysis are in progress.

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